2012 Advanced Space Propulsion Workshop

FFRE Powered Spacecraft

28November 2012

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What is NIAC ?

NASA Innovative Advanced Concepts

A program to support early studies of innovative, yet credible visionary concepts that could one day “change the possible” in aerospace

Exploration Technology Today
An Analogy

Launch

Exploration Technology Today

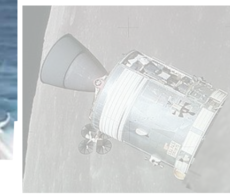
An Analogy

Staging

Launch

Exploration Technology Today

An Analogy



Burnout

Staging

Launch

Exploration Technology Today

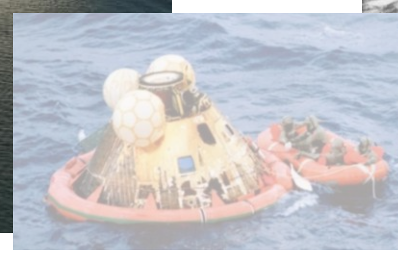
An Analogy

Launch

Staging

Burnout

Safely Home!



Why Would You Want To Explore Like This?

The Reason Why

Because That’s The Best We Can Do Now

The Reason Why

Viewpoint

The ephemeral 'advanced propulsion'

New technologies with the promise of more affordable, more efficient, and safer propulsion for space launch currently seem to be out of reach. That however, does not mean that we should stop searching

by *Jerry Grey*
Editor-at-Large

24 AEROSPACE AMERICA/MARCH 2012

"…. All in all, the near-to-medium prospects for applying 'advanced propulsion' to create a new era of space exploration are not very good."

Because That's The Best We Can Do Now

The Reason Why And An Answer


March 2012

AEROSPACE AMERICA

REAL ESTATE IN FREQUENCY SPACE

Viewpoint

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A FISSION FRAGMENT ROCKET ENGINE:

Engine Attributes:

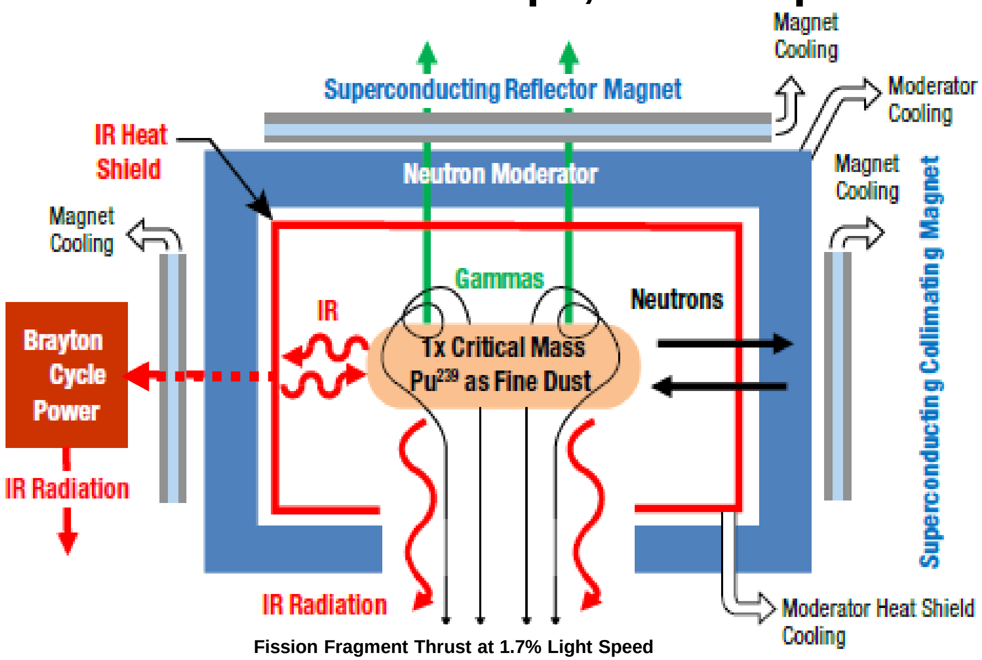
- **Far Less Propellant Than Chemical Or Nuclear Thermal (I_{sp}~500,000s)**
- **Far More Efficient Than Nuclear Electric (100X Thrust)**
- **Far Safer Than Nuclear Thermal (Charge Reactor In Orbit, Radiation Leaves Solar System At >1% Light Speed)**

Spacecraft Impact:

- **More Payload**
- **Faster Travel**
- **Unlimited Electrical Power**
- **Enhanced Astronaut Safety**

Principles of FFRE

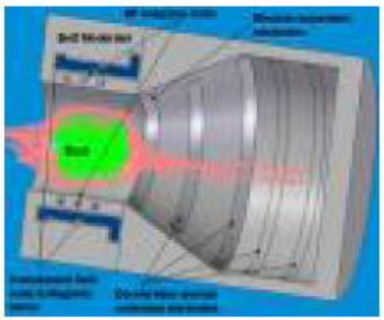
- Reactor Core Uses Submicron Uranium Dust Grains
- Fissioning Low-Density Dust Is Radiatively Cooled.
- Moderator Reflects Neutrons To Keep Dust Critical
- Carbon-Carbon Heat Shield Reflects IR Away From The Moderator.
- Superconducting Magnets Direct FFs Out Of Reactor.
- Electricity Is Generated From Heat Shield Coolant
- Reactor Hole Provides: Heat Escape, FF Escape At 1.7% Light-Speed



FFRE History

Original Spinning Brush FFRE

1986: George Chapline's "Spinning Brush" FFRE: Uranium coated carbon fiber permits half the fission fragments to escape, providing thrust. The other half heats up so fibers rotated out of reactor to cool.



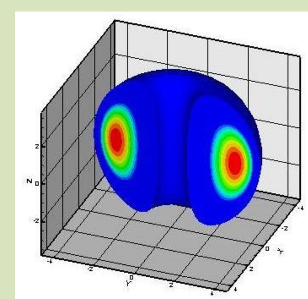
Dusty Plasma FFRE Creation

2005: Dr. Rod Clark creates "Dusty Plasma" FFRE: Fissioning uranium dust maximizes both fission fragment escape and radiative cooling, increasing efficiency and permitting reactor operation at Gigawatts of power.

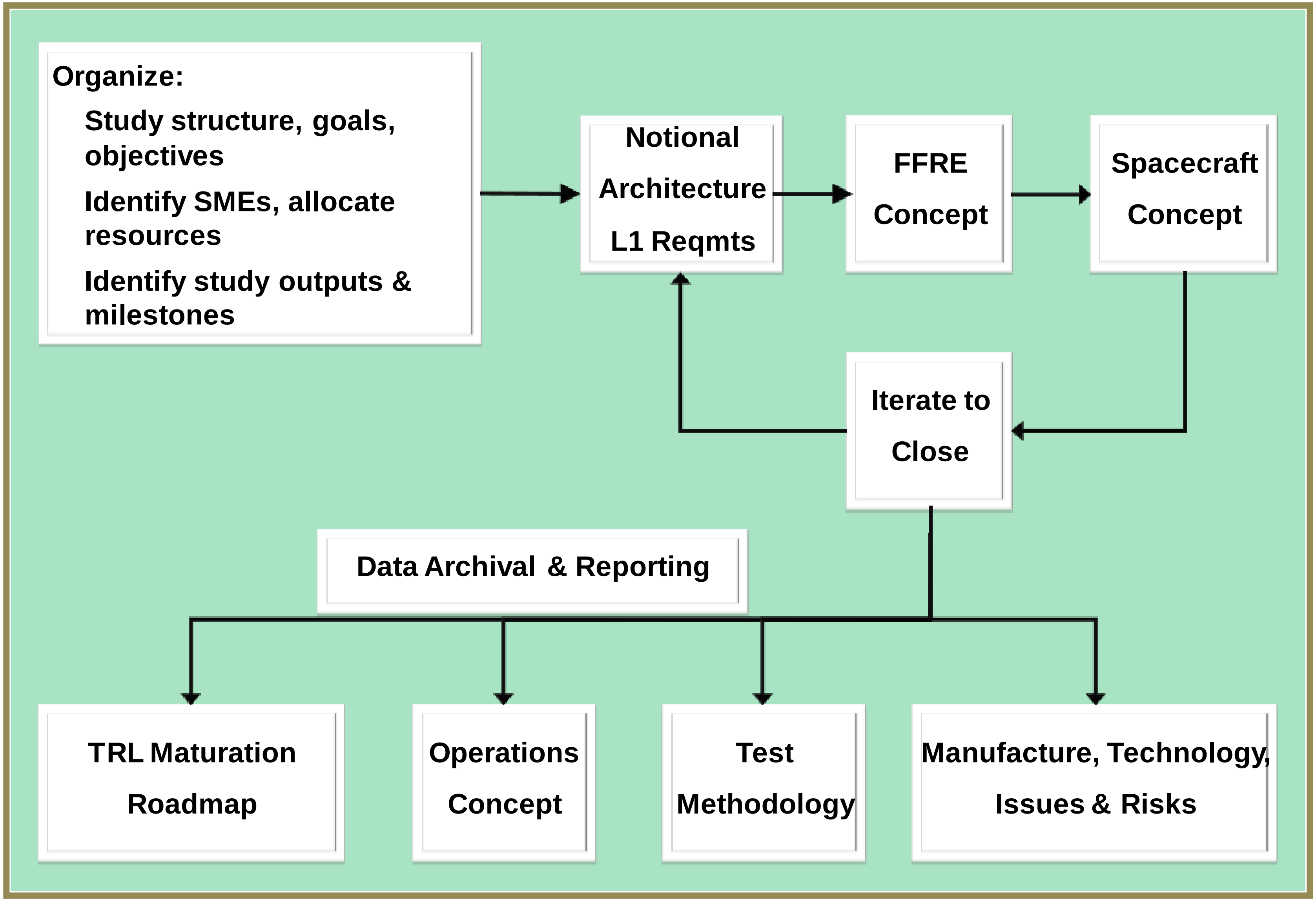
Grassmere Dynamics, LLC

- **Engineering & Consulting**
- **40 Years Of Combined Experience In Engineering Design, Materials, Testing & Quality Assurance.**
- **Specialty Modeling Skills:**
  - Computational Fluid Dynamics (CFD)
  - Magneto Hydrodynamic Plasma (MHD)
  - Nuclear (Radiation, Reactor Design & Performance)
  - Optical

3D Simulation Of Tokomak Nuclear Fusion Reactor Magnetically Confined Plasma Using Grassmere Code



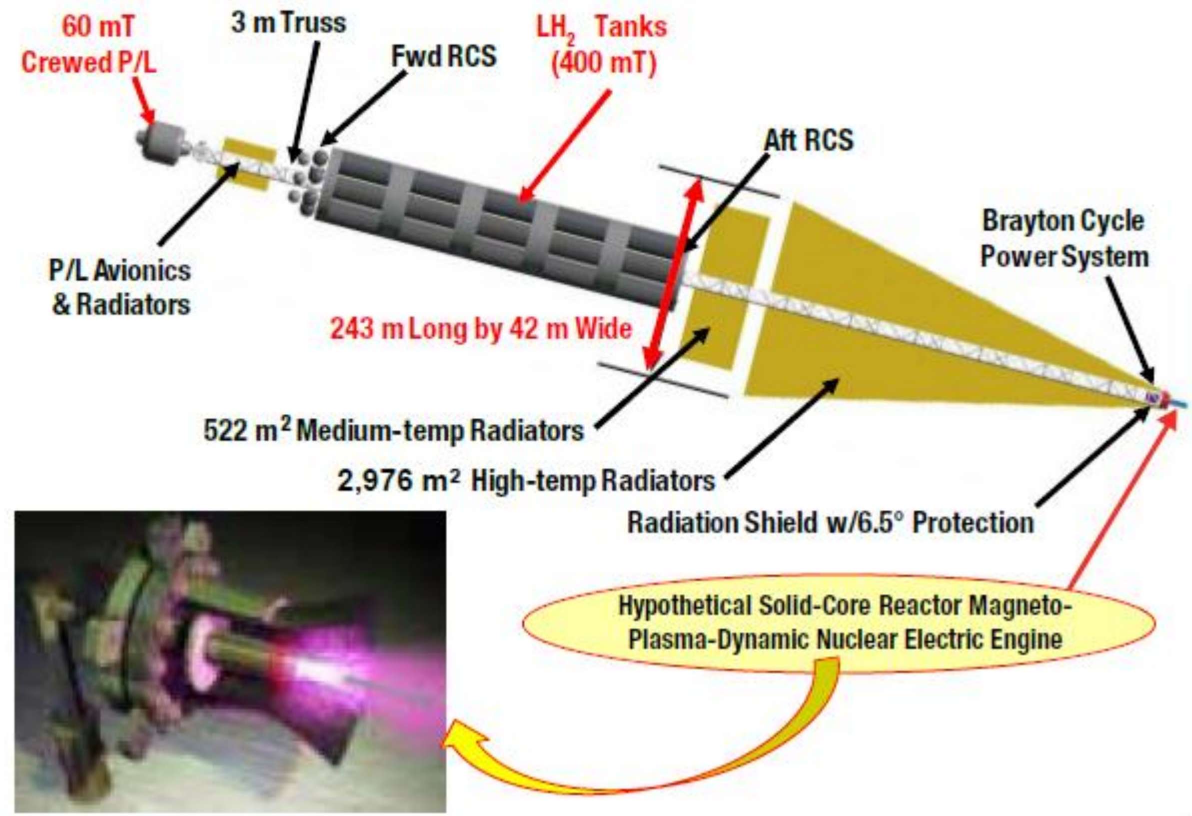
Study Approach



Study Groundrules

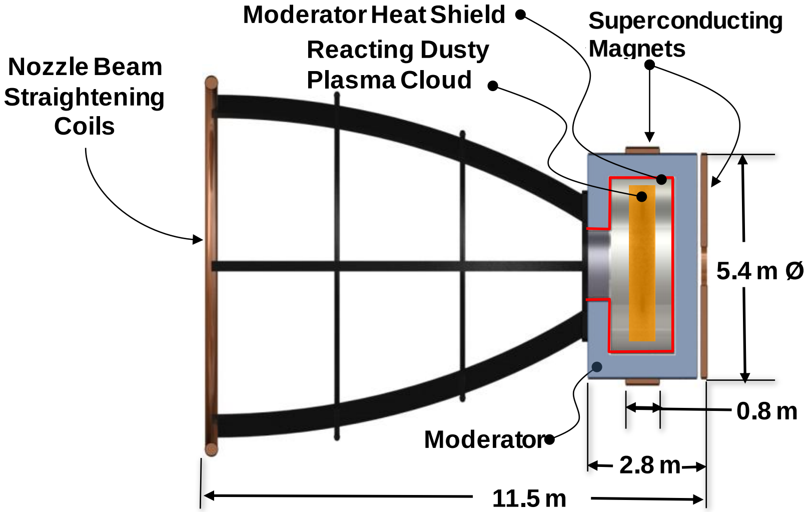
Spacecraft and mission based on 2004 Human Outer Planet Exploration (HOPE) study
- 60 mT crewed payload on roundtrip mission to Callisto

- Propulsion was hypothetical nuclear electric magneto-plasma-dynamic thrusters (6 NEMPD engines, 33 MW each, providing ~22-lb thrust at 8,000 s delivered I_{sp} using hydrogen as propellant)
  - 1 FFRE substituted for 6 NEMPD engines
- All impacted spacecraft subsystems to be redesigned



FFRE Design Status

Base FFRE Design



Master Equip List Mass incl 30% MGA	
FFRE System Total, mT	113.4
Nozzle	6.4
Magnetic Mirror	28.6
Exit Field Coil	11.1
Moderator	51.2
Moderator Heat Shield	0.1
Control Drum System	0.7
Electrostatic Collector	0.3
Dust Injector	7.2
Shadow Shield	7.8

Distribution	(MW)
Total Reactor Power	***1,000***
Neutrons (30% to FFRE)	24.2
Gammas (5% to FFRE)	95.6
Other	70.2
Thermal (IR)	699
Jet Power	**111**

Performance	
Thrust	**43 N** (9.7 lbf)
Exit Velocity	**5170 km/s**
Specific Impulse	**527,000 s**
Mass Flow	**0.008 gm/s**

Revised FFRE Designs

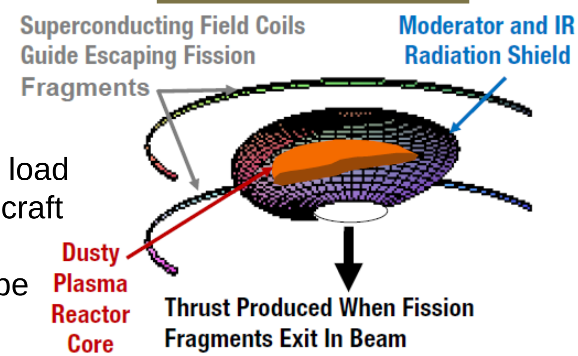
Generation 1

Attributes:

- ❑ Ellipsoid Moderator
- ❑ Ring Magnets

Assessment:

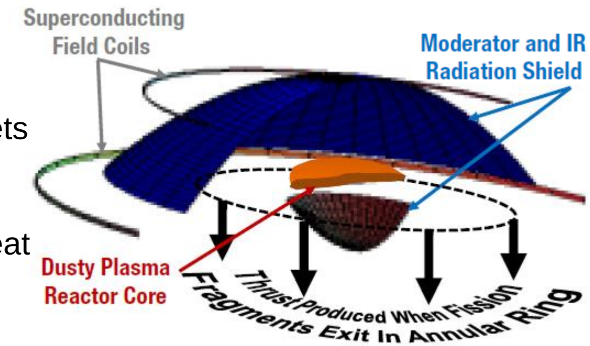
- ❑ Reduced heat load so less Spacecraft radiator mass
- ❑ Complex Shape Moderator
- ❑ Thrust & I_{sp} unchanged



Generation 2

Attributes:

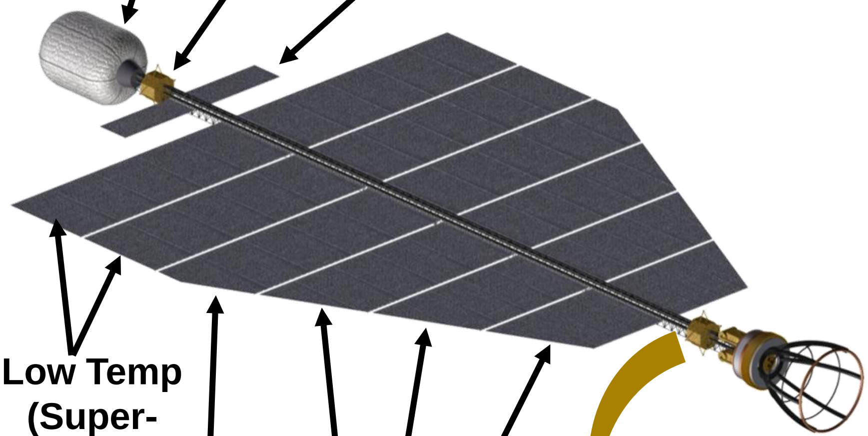
- ❑ Dual Paraboloid Moderator
- ❑ Ring Magnets

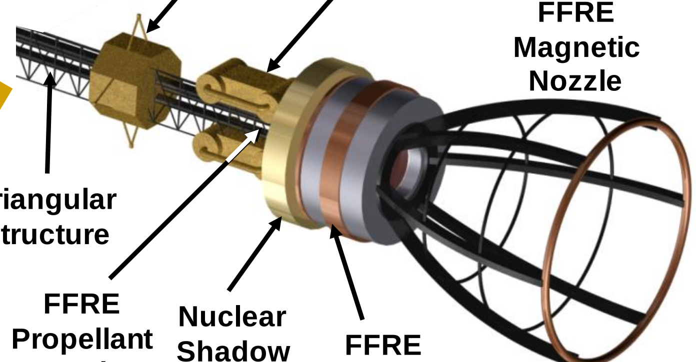


Assessment:

- ❑ Reduced heat load so less Spacecraft radiator mass
- ❑ Complex shape moderator, difficult to support & cool, weighs more
- ❑ Thrust: 2X (86 N, 19 lbf)
- ❑ I_{sp} unchanged (527,000 s)

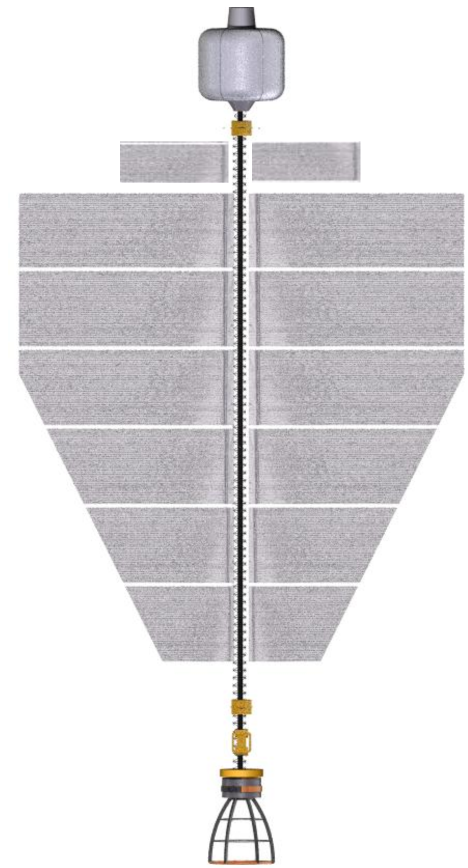
Spacecraft Concept Overview



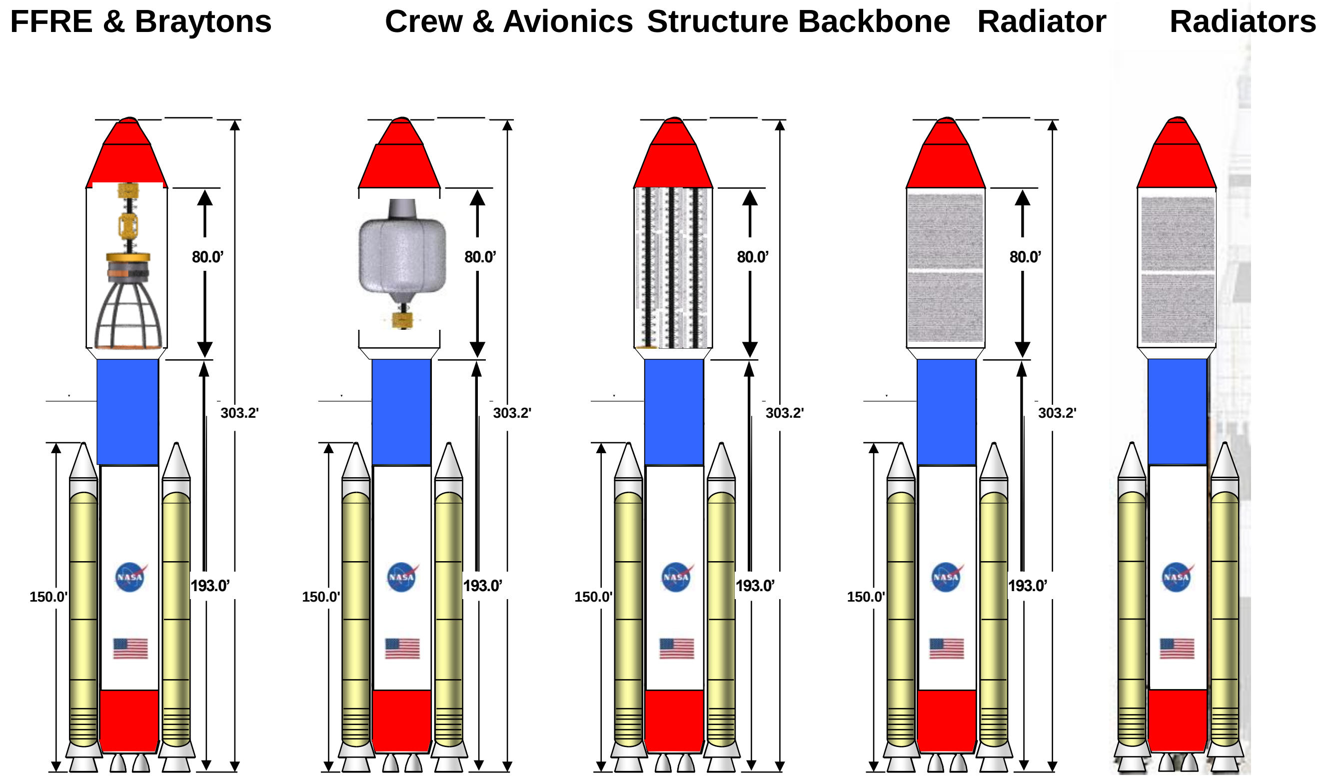


Vehicle	
Payload (Crew/Science Equip.) (mT)	60
Total Mass (mT)	303
Dry Mass (mT)	295
Propellant Mass (mT)	4
Overall Length (m)	120
Overall Span (m)	62
Total Radiator Area (m^2)	6,076
Performance	
Total Power (MW)	1,000
Thrust (N)	43
I_{sp} (s)	527,000
Vehicle Acceleration (g)	3e – 04

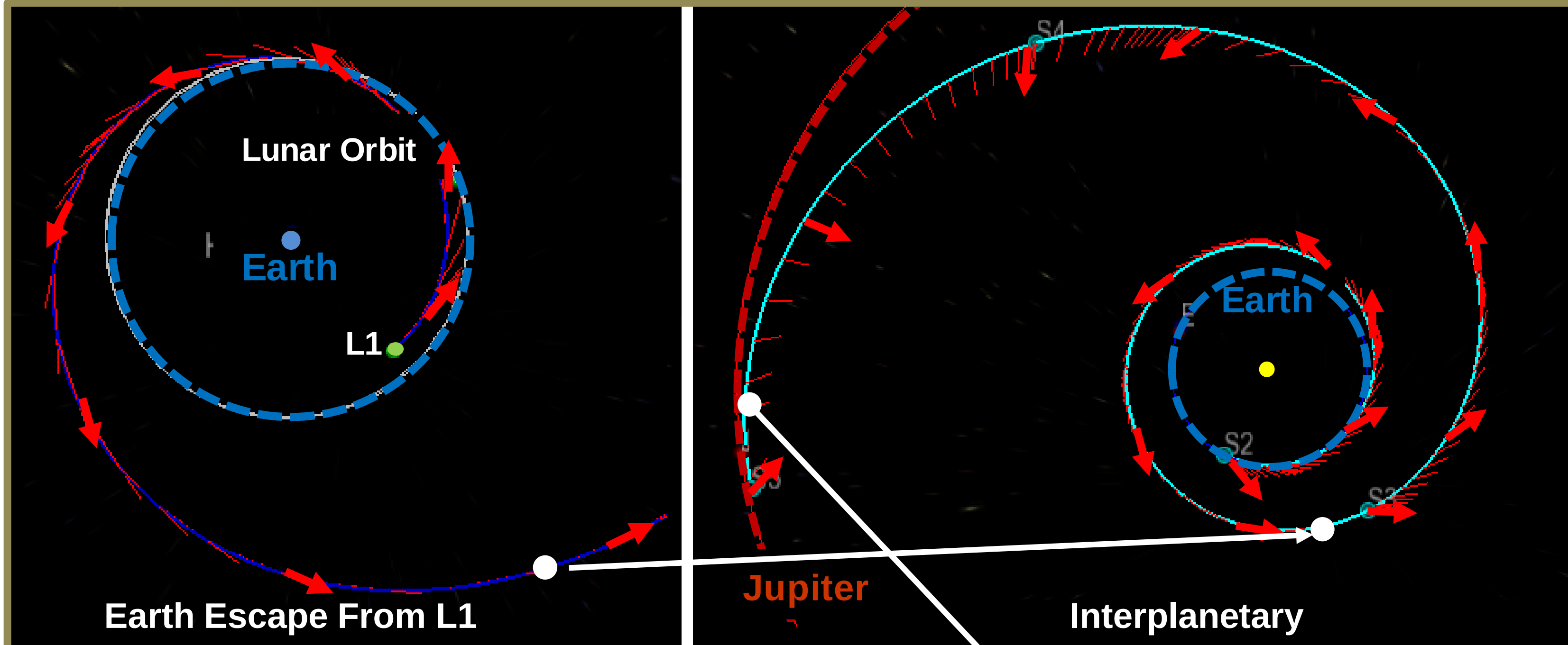
Spacecraft/Typical SLS Packaging

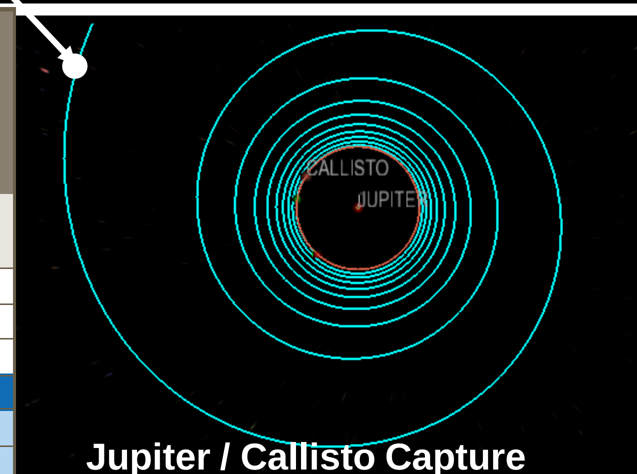


Payload Packaging, hypothetical 12m shroud and >120mT capacity



Spacecraft Performance
(First FFRE / Spacecraft Assessment)





Intitial FFRE Propelled Spacecraft Mission Performance
1st Generation FFRE: 43 N Thrust 527.000s I_{sp}
Spacecraft is acceleration limited

Outbound Trajectory Results	Segment Time (Days)	Thrust Time (Days)	CUM Nuclear Prop (Kg)
Earth Spiral — Out	55	55	40
Interplanetary	2,106	2,161	1,553
Jupiter Spiral — In	503	2,665	1,915
Stay Time at Callisto: ~330 Days			
Total Elapsed Mission Time	5,850 Days (16.0 Years)		
Total Nuclear Fuel Used	4 mT		

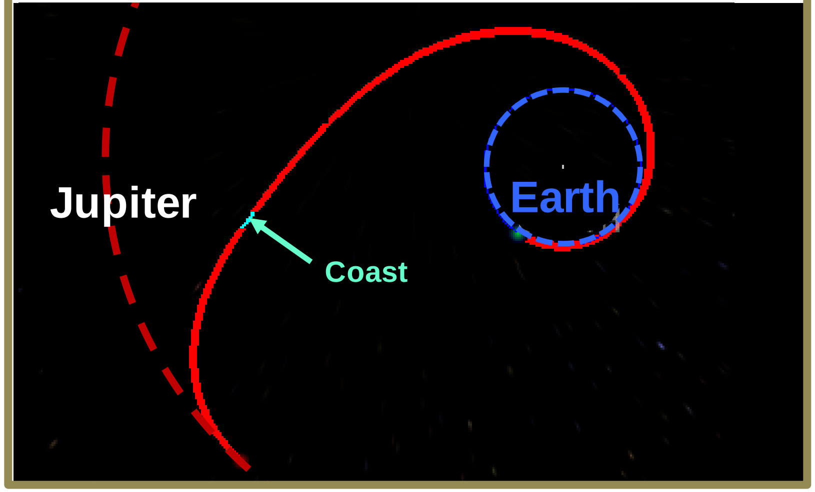
Performance Trades

Effect on Mission Of 2nd Generation FFRE Design

FFRE
- Thrust: 2X (86N)
- I_{sp}: 527,000s

Spacecraft
- Assumed no change (conservative)

Mission
- ~8 years round trip
- Spiral out and in times halved
- Small coast period in interplanetary flight
- Propellant: ~4 mT nuclear

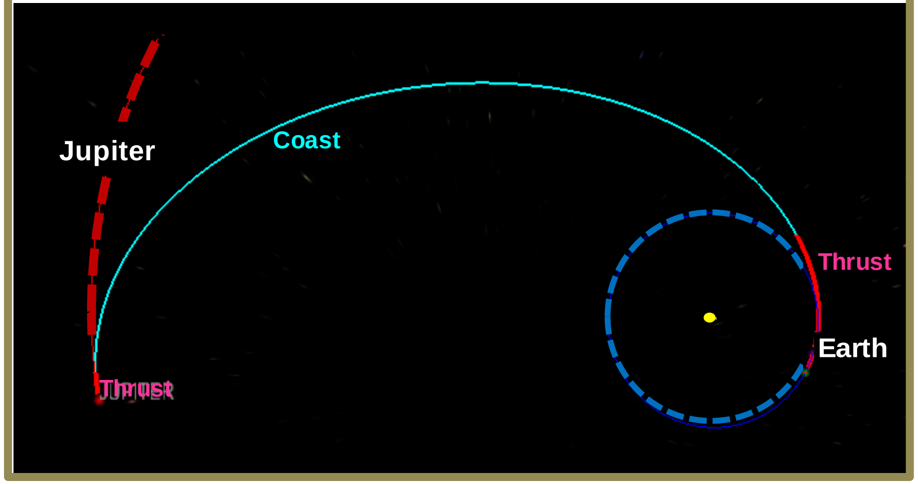


Effect on Mission Of Adding an "Afterburner" to FFRE Design

FFRE
- Fission fragments accelerate an inert gas added to nozzle via friction, adding thrust & decreasing specific impulse
- Thrust: 430N, I_{sp}: 52,700s (notional)

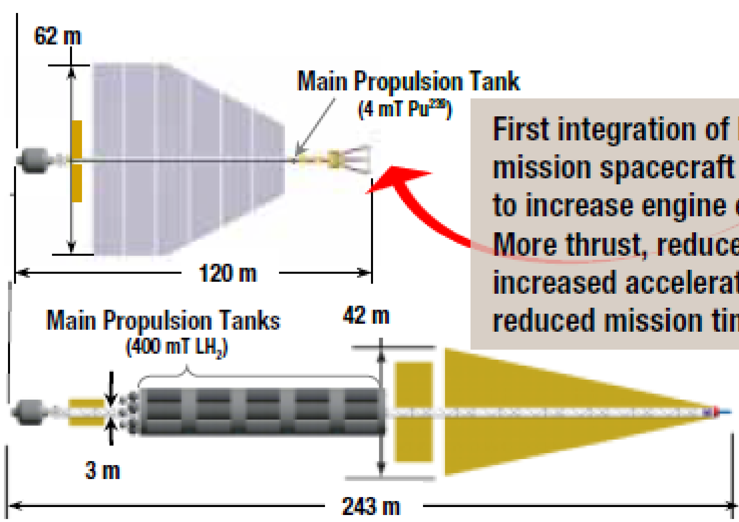
Spacecraft
- Added "propellant" and tankage

Mission
- ~6 years round trip
- From Earth: 4 days, Into Jupiter: 40 days
- Interplanetary Coast: 950days
- Propellant: 0.3mT nuclear, 22mT gas



Spacecraft Comparison

Vehicle	HOPE	FFRE
Payload (Crew/Science Equip) (mT)	60	60
Total Mass (mT)	890	303
Dry Mass (mT)	460	295
Propellant Mass (mT)	400	4
Overall Length (m)	243	120
Overall Span (m)	42	62
Total Radiator Area (m^2)	3498	6,076
Performance	**HOPE**	**FFRE**
Total Power (MW)	34	1,000
Thrust (lbf)	126	9.7
I_{sp} (s)	8,000	527,000
Vehicle Acceleration (g)	14e-4	3e-4
Outbound Trip Time (days)	833	2,665
Return Trip Time (days)	693	2,854
Total Mission (years)	**HOPE 4.5yrs?**	**8-16 yrs**

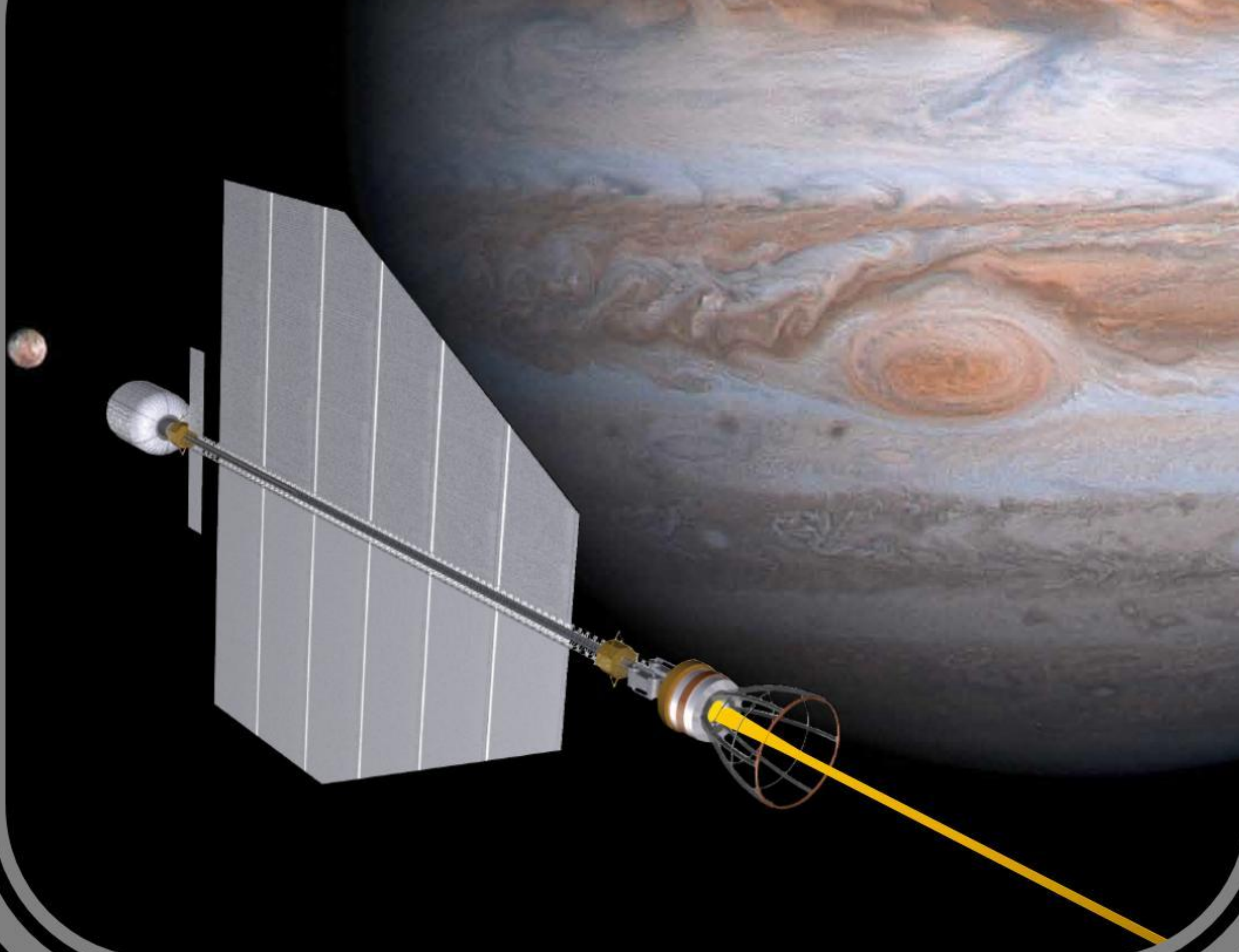


First integration of FFRE & mission spacecraft shows need to increase engine efficiency: More thrust, reduced mass, increased acceleration, & reduced mission time.

What Is Learned So Far

- A FFRE is credible – ordinary engineering, ordinary physics. NO MIRACLES.
- A FFRE-propelled spacecraft is game changing to travel in space. A spacecraft with a heavy payload can depart for and return from many solar system destinations. NO REASSEMBLY REQUIRED.
- Our first constructs of a FFRE are grossly inefficient. We are like a Ford Model T engine. Only a few ways of improving performance of the FFRE and spacecraft have been considered.

THERE'S MUCH WORK TO DO.



Lighting The Afterburner On A Fission Fragment Rocket Engine

FY 13 Center Innovation Fund Study Award

The Next Step: